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Manufacturing and trimming of a low-cost industrial thick-film force sensor

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Abstract: This work describes the design, fabrication and laser trimming aspects of a low-cost compressive force sensor with analogue signal conditioning, designed for a medical syringe pump. First, the general design aspects are discussed, in view of facile and reliable batch production and measurement performance. Then, the circuit's trimming procedure is presented, featuring single-pass adjustment of sensor output in its final state, i.e. with all components mounted, without prior passive resistor trimming.

Key words: thick-film technology, force sensors, manufacturing, trimming

1. INTRODUCTION

Due to their moderate cost, straightforward manufacturing and good reliability, thick-film load sensors (force, pressure, and torque) find wide use in industrial products [1]. For monitoring an instrument such as a syringe pump, no high precision is required, as the force will vary rather widely, according to temperature (viscosity of the fluid), type of fluid, friction of different syringes, etc. However, in such a safety-critical application, there is still a need to reliably recognise forces outside a "reasonable" range, which is user-defined for a given fluid and syringe, in order to raise a malfunction alarm upon circumstances that may endanger the patient (L = low pressure, H = high pressure):

- Electronics / motor malfunction: pumping stopped (L),too slow (L) or too fast (H)
- Syringe not correctly attached and sliding (L)
- End of syringe travel – syringe empty (H)
- Infusion tube severed or unplugged (L)
- Infusion tube obstructed or crushed, e.g. by furniture (H)

To this end, a simple compressive force sensor has been developed (Fig. 1), based on ring-on-ring bending of the substrate [2,3]. This work gives details on design and trimming procedure, with an analysis of the defective samples an actual pilot production run, with implications on parameter adjustments.

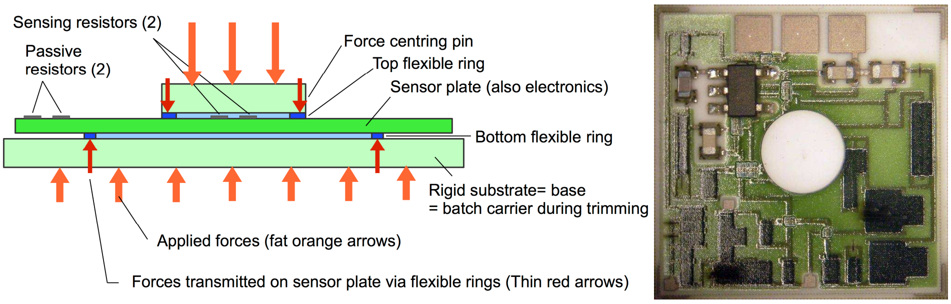

Fig. 1. Developed 'CentoNewton' force sensor: working principle (left) and photograph of first version (right, version A).

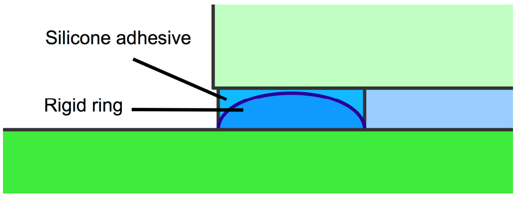

Fig. 2. Solution for flexible joints yielding reasonable compliance and friction avoidance (silicone) and position definition (rigid ring, thick-film glass-based dielectric in version A and mineral-filled epoxy in version B).

2. GENERAL SENSOR DESIGN AND PRODUCTION PROCESS

The sensor was designed with the application in mind, i.e. with priority set on realising a low-cost, rugged device that is easy and straightforward to produce, rather than a "metrological" sensor.

2.1. Overall working principle

The ring-on-ring [4-6] sensor geometry in principle allows for a very simple device (Fig. 1): a flexible plate, carrying a Wheatstone bridge with a pair of sensing piezoresistors in the middle and a complementary inactive pair, is loaded between a "button" and a rigid base. This configuration is more suitable for the mid-range forces measured here (up to ~40 N) than the cantilever one, which is optimal for small forces up to ~2 N [7].

Given the size of the flexible sensing plate, the electronics may reside directly on the sensing plate, i.e. there are no other electrical contacts to be made except the three (supply, ground, signal) required to connect the device to the outside world.

2.2. Flexible mechanical joints

The main challenge for such a device lies in the lateral friction developing at the contact area during bending of the sensor [2,3], yielding signalhysteresis. This was alleviated using the simple solution of combining a rigid ring (for good definition of position) with a soft silicone adhesive (Fig. 2), resulting in acceptable residual hysteresis, down to ~1% of full scale [3], with a simple and straightforward process.

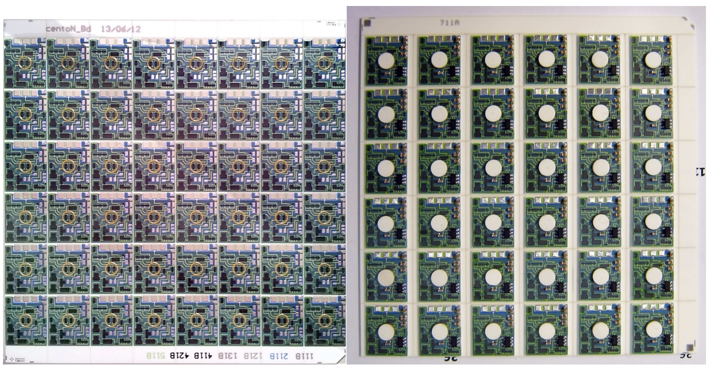

Fig. 3. Batch of "sensor" circuits of version B (left, screen-printed, before mounting of components), and complete sensors (right, components mounted on circuits, then circuits individualised and attached onto the base).

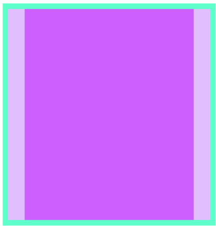

Fig. 4. Comparison of dimensions of base with versions A & B of the sensing plate; the base has to be larger than the sensing plate in order to allow batch mounting and trimming, and ideally sufficiently larger in one direction to facilitate individualisation.

2.3. Batch fabrication

The sensor is based on two thick-film substrates (sensing plate and base, Fig. 3), with the sensing plate carrying essentially all the layers; the base is basically only printed with the silicone adhesive to assemble the sensing plate. The overall process flow for the sensing circuits is as follows:

1) Thick-film production of sensing plate substrates, including rigid rings at top and bottom (Fig. 2)
2) Mounting and soldering of electronics components (amplifier chip and capacitors for simple analogue circuit)
3) Dispensing silicone adhesive (Dow Corning Q5-8401) onto top rigid rings (Fig. 2) and gluing ceramic buttons
4) Individualisation of the sensing circuits by snapping off

The overall fabrication of the complete sensor subsequently treats the whole sensing circuit as a "component", and consists of the further four steps:

5) Screen printing silicone adhesive onto the base using the same silicone adhesive (Dow Corning Q5-8401), and gluing the sensing circuits
6) Active trimming (no prior passive trimming – see subsequent section)
7) Individualisation of the complete sensors by snapping off
8) Final control and packaging

Individualisation of the sensors turned out to be problematic for version A (Fig. 1 / Fig. 4): the size difference between circuit and base was too small, yielding a margin of only 0.38 mm, which is insufficient for reliable and convenient snap-off. As the sensor was already in production and a change of the base was therefore no longer possible, a major redesign had to be carried out, resulting in a circuit smaller in one direction. This also has the advantage of allowing more sensors per 'circuit' substrate than the previous version (8×6 = 48 vs. 6×6 = 36).

3. TRIMMING

In order to simplify production, there is no "passive" trimming step of the screen-printed; all trimming operations are performed after mounting of the sensing circuits onto the base. The procedure consists of a) coarse offset compensation, b) gain configuration, c) offset pre-trimming, d) span trimming, and e) final offset trimming.

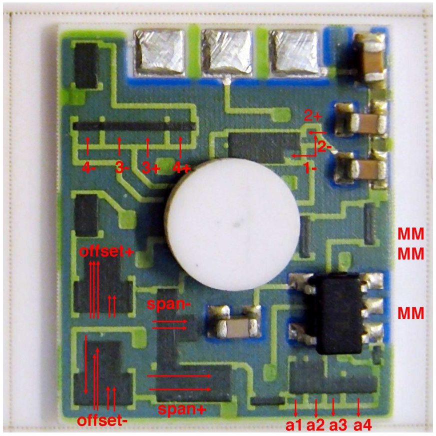

Fig. 5. Version B of sensor, with trim cuts drawn. MM = marking, 1…4± = offset discrete trim cuts, offset± = standard offset trim, a1…a4 = span discrete trim cuts, span± = standard span trim.

To allow a large degree of offset and gain adjustability, while ensuring sufficient resolution and stability, discrete trims, by cutting conductive links, are combined with standard resistor trims. Discrete adjustments combine high amplitude and stability (no microcracks in resistors), with the standard trims providing the high resolution. To ensure a large trimming range with no gaps, several discrete trimming resistors with different amplitudes (1…4, a1…a4: decreasing amplitude) are printed for both offset and span.

4. CONCLUDING REMARKS

We show in this work that a combination of available and standard production and trimming methods allow simple and straightforward production of a low-cost thick-film force sensor. One-step trimming is however associated with two further complications beyond the scope of this work that require specific measures: 1) process variations between resistor compositions, and 2) saturation of the amplified output.

5. REFERENCES

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